

Effect of Cr on Friction and Corrosion Performance of Tetrahedral Amorphous Carbon Coating Prepared by Filter Cathodic Vacuum Arc

by Qingfu Xiao | Lang Hu | Hong Liu | Zhenhuai Yang | Jihua Laboratory | Jihua Laboratory | Jihua Laboratory | Jihua Laboratory

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Keywords: Tetrahedral amorphous carbon, corrosion performance, filter cathodic vacuum arc, friction performance

Tetrahedral amorphous carbon (ta-C), compared with DLC, has high hardness, low friction coefficient, and good corrosion resistance. However, the high sp³ contents of ta-C film means the higher stress than the DLC film. Adding buff layers or doping are effective methods to reduce the stress. In this paper, ta-C films were deposited by Filter Cathodic Vacuum Arc (FCVA) with optimized parameters, such as bias and coil current. The Cr element, deposited by High-power impulse magnetron sputtering, was introduced to adjust the sp³ content in the film, and then control the performance of the ta-C film. The effects of different forms and contents of Cr on the stress and properties of were systematically researched. The microstructure, chemical bonding state, frictional, and electrochemical properties of the coatings were studied by HRSEM, Raman, XPS, nanoindentation, ball-on-disk tribometer, and electrochemical workstation. The results indicate that with an increase in Cr element content, CrC nanocrystals gradually form and embed in the ta-C film, leading to a decrease in the sp³ bond content and hardness of the film, resulting in an increased wear rate. Additionally, the presence of CrC nanocrystals provides pathways for corrosive ions, leading to a decrease in corrosion resistance in a 3.5wt% NaCl solution. These findings provide important insights for further optimizing the performance of tetrahedral amorphous carbon coatings.

Effect of Cu content on the mechanical and tribological properties of MoN/Cu coatings deposited by HiPIMS

by Fuqiang Li | Wei Dai | Qimin Wang | Guangdong University of Technology, China | Guangdong University of Technology, China | Guangdong University of Technology, China

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Keywords: MoN/Cu coatings; Mechanical properties; Tribological properties; HiPIMS

The application of self-lubricating protective coatings for critical parts in aerospace and marine applications can improve their service life and ensure reliable operation at high temperatures and in harsh environments. Molybdenum-based coatings exhibit excellent mechanical characteristics and provide a readily shearable oxide MoO₃ lubricating phase during friction. Cu was introduced to improve the mechanical and tribological properties of the coating, with the goal of investigating its potential use as a temperature-adapted lubricant. In order to investigate the mechanical and tribological properties of MoN/Cu coatings at ambient and medium to high temperatures, High-power pulsed magnetron sputtering (HiPIMS) was used to prepare coatings with Cu contents ranging from 1.5–19.3 at.%. Cu columns were inlaid on a planar Mo target. The results show that adding Cu causes grain refinement, and the coating's phase structure is primarily fcc-Mo₂N with amorphous Cu. The coating's hardness of 29.5 GP at Cu-3.8 at.% is due to the composite of the two phases, fcc-Mo₂N and δ-MoN. The coating's coefficient of friction and wear rate can be as low as 0.28 and 4.5×10⁻⁸mm³/N·m at room temperature. Cu-3.8 at.% shows excellent tribological properties at 400 °C because of the oxidizability of δ-MoN. The coefficients of friction and wear rate are 0.34 and 6.4×10⁻⁷mm³/N·m, respectively. And the high Cu content increases the coefficient of friction because MoO₃ dominates the friction process at 400 °C. At 500°C, the amount of MoCuO₄ that forms in the wear marks increases as the Cu content increases. This leads to a high wear rate of 5.9 × 10⁻⁵mm³/N·m and a low coefficient of friction of 0.27 for Cu-19.3% at.%. For Cu-19.3 at.%, the friction coefficient and wear rate are 0.34 and 6.4 × 10⁻⁷ mm³/N·m, respectively.

High-temperature thermal stability and oxidation resistance of TiAlCrTaWN high-entropy coatings deposited by cathodic arc evaporation

by Bin Peng | Yu X. Xu | Qimin Wang | Guangdong University of Technology, China | Guangdong University of Technology, China | Guangdong University of Technology, China

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Keywords: Hard coatings; High-entropy nitrides; Thermal stability; Oxidation resistance

Alloying is a well-established method to tailor the structure and properties of TiAlN coatings. This study involved the synthesis of multicomponent coatings, specifically TiAlN, TiAlCrN, TiAlTaN, TiAlWN, and TiAlCrTaWN, using cathodic arc evaporation and the investigations on thermal stability and oxidation resistance. All investigated coatings exhibit a face-centered cubic structure in which Cr, Ta, and W are dissolved in TiAlN to form solid solutions, resulting in a high hardness exceeding 32 GPa. Significant spinodal decomposition and age-hardening can be obtained upon annealing. Ta- and W- addition performs better than Cr, which can delay the formation of wurtzite AlN of TiAlN coating by ~ 100 °C. Compared with single-element alloying, the co-alloying of Cr, Ta, and W furtherly broadens the temperature range of spinodal decomposition and retards the subsequent formation of the wurtzite AlN. The TiAlCrTaWN coatings with high mixing entropy can remain high hardness at 33.5 GPa at 1100 °C, while the hardness of other coatings drops sharply to below 30 GPa at 1000 °C. The rapid diffusion of Cr in the initial oxidation stage to form a protective (Al, Cr)₂O₃ scale is conducive to developing the Al-rich top protective oxide scale. The slow diffusion rate of Ta and W elements tends to dissolve in the Ti-rich oxide sublayer, which promotes the direct formation of rutile TiO₂ and effectively reduces the oxygen vacancy concentration in the inner layer, thereby inhibiting the inward diffusion of oxygen. Co-alloying with Cr, Ta, and W leads to optimal oxidation resistance of TiAlN coatings at 1000 °C.

Investigating the energetic band diagrams of oxygen-terminated CVD grown e6 electronic grade diamond

by Kang LIU | Harbin Institute of Technology

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Keywords: Diamond, Energetic band, Fermi level, Oxygen terminal, Pinning effect, Surface states

Oxygen-terminated type IIa (OT-IIa) diamond with oxygen suspended in the form of a ketone bond (C=O) was synthesized via acid treatment. The Fermi level at 3.23 eV below the conduction band minimum for the OT-IIa diamond surface was measured experimentally, while that at 0.97 eV for the bulk was calculated theoretically. An acceptor model of the surface states was developed, employed, and combined with an upward-bending band diagram to compensate this energetic band difference between the surface and bulk of OT-IIa diamond. A Schottky barrier height of 3.15 eV between gold and the OT-IIa diamond was also measured. In addition, we also inferred the downward-bending band diagram for the surface of oxygen-terminated p-type diamond doped with boron. This work complements the semiconductor theory concerning diamond and will be helpful to analyze and improve the performance of devices based on oxygen-terminated diamond.

Investigation on CrN transition layer on the mechanical properties and corrosion resistance of DLC coating

by Jianming Wang | Southeast University

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Keywords: Cr/CrN/DLC thin films □ Phase composition □ Mechanical properties □ Corrosion resistance

This study employed the non-equilibrium magnetron sputtering ion plating technique to fabricate Cr/CrN/DLC thin films with different CrN transition layer thicknesses on a 316 stainless steel substrate (Cr/DLC, Cr/CrN-0.5h/DLC, Cr/CrN-1.0h/DLC, Cr/CrN-1.5h/DLC). The morphology, phase composition, adhesion strength, hardness, wear resistance, and corrosion resistance of the prepared Cr/CrN/DLC thin films were systematically investigated using SEM, XRD, Raman spectroscopy, scratch tester, nanoindentation tester, micro-Vickers hardness tester, electrochemical workstation, and friction-wear tester. The results indicate that an increase in CrN transition layer thickness leads to an increase in residual stress in the coatings, resulting in an overall shift of diffraction peaks towards higher angles. The adhesion strength of the coatings exhibits a trend of initially increasing and then decreasing, with Cr/CrN-1.0h/DLC showing the highest interfacial adhesion strength, which is 22.9% higher than that of Cr/DLC. The surface hardness of the coatings is similar, but with increasing load, Cr/CrN-1.5h/DLC demonstrates better resistance to plastic deformation. Additionally, Cr/CrN-1.0h/DLC exhibits excellent wear resistance, with the wear mechanism mainly being abrasive wear, accompanied by graphitization transformation at the friction interface. Furthermore, it was found that the addition of a CrN transition layer shifts the corrosion potential of the coatings in the positive direction, reduces the corrosion current, and increases the polarization resistance, with Cr/CrN-1.0h/DLC showing the smallest corrosion potential (-0.174 V), the lowest corrosion current density ($1.15 \times 10^{-8} \text{ A} \cdot \text{cm}^{-2}$), and the largest polarization resistance ($7.56 \times 10^6 \text{ } \Omega \cdot \text{cm}^2$), thereby improving the corrosion resistance of DLC.

Investigation on the cavitation erosion of graphite-like carbon coatings strengthened by periodic gradient bias

by Zhiquan Huang | Jian Chen | Jiangsu Key Laboratory of Advanced Metallic Materials, School of Materials Science and Engineering, Southeast University, Nanjing, 211189, China | Jiangsu Key Laboratory of Advanced Metallic Materials, School of Materials Science and Engineering, Southeast University, Nanjing 211189, Chin

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Keywords: Physical vapor deposition; GLC coating; Periodic gradient bias; Marine Application.

In marine hydrodynamic systems, metal components face significant threats from cavitation, sand erosion and seawater corrosion. Graphite-like carbon (GLC) coatings can be well developed to resist wear and corrosion due to their high hardness, low friction coefficient and good corrosion resistance, but their high internal stress limits their wide application in marine applications. In this study, GLC coatings with low internal stress and excellent cavitation resistance were successfully developed by designing periodic gradient bias. The GLC coating has not only high load-bearing capacity, coating adhesion, mechanical properties and corrosion resistance, but also excellent cavitation resistance in distilled water and simulated seawater. In addition, the failure mechanism of GLC coating under cavitation environment was analyzed, and the evolution process of GLC coating composition, structure and morphology during cavitation was studied. These findings not only provide practical solutions for improving marine performance of metal parts, but also provide insights into the design of PVD GLC coatings.

Mechanical properties and microstructure of sputtering MoN/MoWN nanolayered coatings

by Hsu Wan Chang | No.2, Lianda, Miaoli 36063, Taiwan.

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Keywords: MoN, MoWN, mechanical properties, microstructure, nanolayer

In This study two types of MoN/MoWN nanolayered films with different thickness ratios were prepared by alternately stacking of molybdenum nitride, MoN, and molybdenum tungsten nitride, MoWN, with a thickness fixed at 25nm and ranging from 25 to 50 nm, respectively, with a total thickness of around 1 μm . The fabrication process employed reactive radio frequency magnetron sputtering, RFMS, technique with Ar and N_2 . The MoN single layer exhibited a nanocrystalline structure, while the MoWN layer displayed well defined crystalline characteristics. Through microstructure analysis, the nanolayered MoN/MoWN with a building bilayer of 25/50 nm/nm exhibited continuous growth of MoWN columnar crystals along $\text{B1-MoN}(111)$. In contrast, the through-layer columnar grain was suppressed by the 50/50 nm/nm MoN/MoWN stacking. Regarding tribological behavior, the M-50/50 multilayer film exhibited a shallower and narrower wear track in comparison to that of the 25/50 MoN/MoWN multilayer film. The enhanced wear resistance was a result of the effective inhibition of continuous growth of columnar crystals by a thicker MoN building layer. Additionally, The MoN/MoWN multilayer film with a 50/50 thickness ratio demonstrated superior adhesion and toughness in scratch testing, as evidenced by the maximum values of Lc1, Lc2, and CPRs.

Microstructure and mechanical properties of DLC films prepared by ion vapor deposition

by Junho Choi | Tokyo City University

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Keywords: DLC film; microstructure; Raman parameters; ionvapor deposition

Diamond-like carbon (DLC) films were prepared by ion vapor deposition, and the microstructure of the films was evaluated by Raman spectroscopy. The negative bias voltages were varied from 0.3 to 4.5 kV during the deposition. With an increase in the negative bias voltages, the Raman G-peak position and I(D)/I(G) ratio increased, and the G-peak full width at half maximum (FWHM(G)) decreased, indicating graphitization of the DLC films. In the low-wavenumber regime, the FWHM(G) increases when the G-peak shifts to higher wavenumbers, reaching a maximum value at around 1555 cm^{-1} , and then decreases. This behavior was due to the structural changes occurring in the DLC films with an increase in the wavenumber. DLC to polymer-like carbon (PLC) transition occurred in the low-wavenumber regime, and DLC to graphite-like carbon (GLC) transition occurred in the high-wavenumber regime. Further, two different trends were observed in the relationship between the hardness of the DLC films and the FWHM(G), originating from the structural change from DLC to GLC and PLC. The microstructural properties of the prepared DLC films were compared to those films deposited using plasma-based ion implantation and deposition.

Multilayer C/C diamond like carbon coatings for load bearing applications: a complete systematic investigation

by Muhammad Usman | City University of Hong Kong

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Keywords: Diamond like carbon, High contact stress, Nanoindentation, Scratch adhesion, Thick multilayer, Tribological performance

Diamond like carbon (DLC) coatings are in focus from last few decades due to its exceptional mechanical and tribological properties. High hardness, low coefficient of friction and wear rate are some of the intrinsic characteristics. Therefore, it is widely used in microelectromechanical systems, automotive sector, tools, laser barcodes scanners etc. However, industrial bearings, load bearing implants and machine elements are high load applications. Single layer DLC has its own limitations: hard DLC possesses high compressive residual stresses and experiences buckling induce adhesion failure under high load whereas soft DLC lacks wear resistance and better mechanical properties [1]. Researchers shifted from single to multilayer architecture in DLC to achieve high hardness and toughness simultaneously [2-4]. Alternate hard and soft layers increase load bearing capacity of the coating compared to hard monolayer [3]. The current research aims to evaluate the impact of overall thickness of multilayer DLC (extending our previous research) on atomic bonding, mechanical properties, scratch adhesion and wear resistance particularly at high contact stress which are missing previously. Therefore, new multilayer DLC coatings are designed with alternate hard and soft layers using closed field unbalanced magnetron sputtering system. Hard to soft layer ratio (1:1) and layer thickness (50nm) are kept constant for all specimens. 0.5 μ m, 1 μ m, 2 μ m, 3 μ m, 4 μ m thick coatings (fig. 1) are deposited onto steel substrate having Cr/CrCx interlayer. Scanning electron microscope, Raman spectroscopy, nanoindenter, scratch adhesion tester and tribometer are employed for characterization of specimens. Raman analysis depicts decreasing ID, IG values and increasing full width at half maximum FWHM(G) trend by increase in coating thickness. Hardness and residual stress are in inverse and direct relation to thickness respectively. Interestingly, scratch adhesion resistance is found to be within same range for all specimens. Moreover, this multilayer DLC design exhibited excellent wear resistance under high loading conditions.

Novel diamond and ta-C composite coatings for efficient heat dissipation in GaN semiconductor devices

by Kesheng Guo | Hu Lang | Qiming Wang | Ji Hua Laboratory | Ji Hua Laboratory | Guangdong University of Technology

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Keywords: GaN device, diamond film, ta-C film, thermal conductivity

The fields of 5G communications, fast charging, and micro-LED displays are increasingly reliant on new semiconductor materials such as gallium nitride (GaN) and gallium oxide (Ga₂O₃), which possess high-frequency and high-power characteristics. During operation, high-frequency and high-power devices generate a significant amount of Joule heat. Additionally, the GaN material itself produces a substantial amount of heat and has low thermal conductivity. These factors can lead to a decline in device performance and a shortened lifespan. To tackle this issue, diamond material has been developed and applied as a heat dissipation technology for GaN devices. However, integrating polycrystalline diamond heat dissipation materials on GaN semiconductor devices presents a major challenge: improving heat dissipation efficiency without degrading semiconductor performance. The study involved the deposition of tetrahedral amorphous carbon (ta-C) films on the surface of a GaN device using the filtered cathodic vacuum arc (FCVA) method. The resulting carbon film ($sp^3 \geq 80\%$) was dense and poreless with a thickness of about 10 nm. Subsequently, a highly oriented diamond film was deposited using the microwave plasma chemical vapor deposition (MPCVD) method. The diamond film has a uniform coverage on the ta-C film, with a thickness of approximately 3 μm and a grain size of around 2 μm . Transient heat reflection measurements revealed that the diamond grains have a thermal conductivity of approximately 1800 W/mK. The isotropic diamond grains effectively promote the lateral and longitudinal diffusion of heat, resulting in a significant improvement in the thermal conductivity of the GaN semiconductor device. This leads to a reduction in the temperature of the working surface by at least 20%. Highly efficient heat dissipating carbon composite films are important for achieving high performance power conversion, communications, radar and other fields.

Probing the structure and property relation of nitride hard coatings at the atomic scale

by Zaoli Zhang | Zhuo Chen | Erich Schmid Institute of Materials Science, Austrian Academy of Sciences | Erich Schmid Institute of Materials Science, Austrian Academy of Sciences

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Keywords: Nitride multilayer, TEM, atomic structure, mechanical property

Transition metal nitrides (TMNs) have found widespread applications in the cutting- and machining-tool industry due to their extreme hardness, thermal stability, and resistance to corrosion. The increasing demand for these nitrides requires an in-depth understanding of their structures at the atomic level. This has led to numerous experimental and theoretical research [1-3]. Using advanced electron microscopy and spectroscopy, our understanding of the structure and property relationships of TMNs has been significantly advanced. Our recent progress achieved will be summarized [1-4].

Firstly, we show a study of a multilayered structure comprising rock-salt (*rs*) structured CrN layers of constant thickness and AlN layers of varying thicknesses, which surprisingly enables the growth of metastable zinc-blend (*zb*) AlN layers for certain layer-thickness combinations. The multilayer exhibits an atomic and electronic structure gradient. A combined experimental analysis based on valence electrons and inner shell electrons allowed the mapping of mechanical properties (bulk modulus) of the multilayer at the nanometre scale. Further, we found that the presence of oxygen impurities causes a remarkable reduction of the bulk modulus of *rs*-CrN[1].

Secondly, a close examination of the TiN/AlN multilayer reveals that nanoindentation may cause a new phase formation, which could be visualized via mapping the fine structure difference (i.e., Ti-L2,3). Using atomic-resolution TEM and STEM/EDXS, we further corroborated such a homogeneous solid-state phase occurred upon loads. [3].

Recently, we found that the deformation of the nitride multilayer could be achieved through unit-scale disturbance. This mechanism leads to a significant enhancement of mechanical properties [4].

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PVD hard oxide coatings for tribological and cutting applications

by Yuxiang Xu | Qimin Wang | Guangdong University of Technology | Guangdong University of Technology

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Keywords: Hard oxide coatings; Physical vapor deposition; Mechanical properties; Wear resistance

Al_2O_3 coatings have exceptional thermal stability and chemical inertness, making them highly suitable as protective coatings for cutting tools. However, the low-temperature and high-efficiency deposition of dense and wear-resistant Al_2O_3 is still challenging and of great technological significance. This study presents the structure, mechanical, and tribological properties of $(\text{Al}, \text{Cr})_2\text{O}_3$ coatings deposited by cathode arc evaporation. Compared to conventional AlCrN, the phase structure of $(\text{Al}, \text{Cr})_2\text{O}_3$ coatings highly depends on the Al content. Also, the substrate bias can noticeably affect the high-temperature wear resistance of oxide coatings. The $(\text{Al}, \text{Cr})_2\text{O}_3$ coating exhibits superior wear resistance at 600 °C with a wear rate of $2.3 \times 10^{-7} \text{ mm}^3/\text{Nm}$, due to a high compressive residual stress achieved with an optimum bias potential.

Furthermore, a hybrid deposition method combining cathode arc evaporation and high-power impulse magnetron sputtering was employed to deposit $\text{Al}_2\text{O}_3/\text{Cr}_2\text{O}_3$ coatings, showing smooth surfaces with reduced droplet defects. The hybrid oxide coatings exhibit a dominated face-centered cubic structure with a nano-multilayer geometry formed by alternating Al_2O_3 and Cr_2O_3 sublayers. Consequently, the hybrid technique is promising for depositing hard oxide coatings with low surface roughness and high hardness for cutting applications.

Research on Deep-sea Anti-tribocorrosion Carbon-based Coatings and Failure Mechanisms

by Peiling Ke | Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences

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Keywords: Carbon-based Coatings, Corrosion Failure Mechanism, Defect Control, Tribocorrosion

Offshore equipment faces significant challenges in high hydrostatic pressure and strong corrosion environments. The synergistic impact of friction and corrosion on the surfaces of essential moving components is heightened, severely constraining the system's ability to long-term durability and safe operation. The amorphous carbon (a-C) coating boasts attributes of elevated hardness, diminished frictional resistance, and commendable chemical inertness, rendering it the epitome of a resolution to combat abrasion for intricate deep-sea mobile components. Based on this premise, we have achieved a multitude of breakthroughs in deep-sea anti-abrasive protective a-C coatings.

Firstly, we employed a sophisticated simulated deep-sea high-pressure testing apparatus in conjunction with micro-in-situ electrochemical analysis, revealing that the critical element triggering coating breakdown is the presence of penetration defects under elevated hydrostatic pressure, which prompt rapid diffusion of the solution within the defect. Concurrently, oxygen infiltrates the coating/substrate interface, exacerbating corrosion-induced deterioration of the metal substrate. Therefore, we implemented a manual intervention procedure during the deposition process, resulting in a notable decrease in the coating's penetration defect density. This led to a reduction in porosity from 5.2% to 2.54%, as well as a decrease in localized pitting. Moreover, the corrosion resistance of the coating was greatly enhanced under both standard atmospheric pressure and 30 MPa of hydrostatic pressure (equivalent to a depth of 3000 m). Furthermore, we crafted a remarkably dense a-C multilayer coating utilizing high-power pulsed magnetron sputtering (HiPIMS) technology. Upon subjecting the optimized coating to long-term corrosion assessment in the depths of the sea, withstanding 15 MPa pressure for 425 hours, the coating/substrate interface remains unmarred while the corrosion current density hovers around $2.04 \times 10^{-9} \text{ A} \cdot \text{cm}^{-2}$. These findings lay a foundation for the design and enhancement of a-C coatings endowed with superior corrosion resistance.

Study on Tetrahedral Amorphous Carbon(Ta-C) composite films application in stainless steel bipolar plates of Proton exchange membrane fuel cells (PEMFCs)

by Xia Zhengwei | Wu Yucheng | Zhang Haibin | Zhang Xinfeng | Liu Dongguang | Hefei University of Technology, Department of Materials Science and Technology, Hefei, Anhui Province, 230009, PR China & Anhui Chunyuan Coating Technology Co.Ltd, Hefei, Anhui Province, 230088,PR China | Hefei University of Technology, Department of Materials Science and Technology, Hefei, Anhui Province, 230009, PR China | Anhui Chunyuan Coating Technology Co.Ltd, Hefei, Anhui Province, 230088,PR China | Anhui Chunyuan Coating Technology Co.Ltd, Hefei, Anhui Province, 230088,PR China | Hefei University of Technology, Department of Materials Science and Technology, Hefei, Anhui Province, 230009, PR China & Anhui Chunyuan Coating Technology Co.Ltd, Hefei, Anhui Province, 230088,PR China

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Keywords: PEMFC, Stainless steel Bipolar plates, Tetrahedral Amorphous Carbon(Ta-C) films, corrosion resistance, interfacial contact resistance

Proton exchange membrane fuel cells (PEMFCs), which converts hydrogen energy directly into electrical energy and water, PEMFCs has received overwhelming attention owing to their potential to significantly reduce our energy consumption, pollution emissions, and reliance on fossil fuels.

The bipolar plates is the major part and key component of PEMFCs stack, which contributes 60%-80% weight and 20-30% costs of the whole stack. Stainless steel bipolar plates enjoys good manufacturability, low cost, and durability among various metal materials. However, to be operated in the harsh acid (pH 2-5) and humid PEMFCs environment, stainless steel would be corroded, and the leached ions will contaminate the membrane. In addition, the passivated film formed on the surface will increase the interfacial contact resistance (ICR).

Surface coatings are essential to metallic bipolar plates, because they are able to enhance corrosion resistance and electrical conductivity. Carbon-based coatings, including amorphous Carbon(a-C) and diamond-like carbon (DLC) coatings, have attracted considerable attention from both academia and industry owing to their superior performance, such as chemical inertness, mechanical hardness, and electrical conductivity. However, article seldom reported Tetrahedral amorphous carbon (Ta-C) films as metallic bipolar plates protective coating of PEMFCs due to the difficulty on preparation. In this paper, the multi-layer Ta-C composite film was produced by customized all- in-one vacuum equipment with magnetron sputtering and vacuum cathode arc-discharge disposition method. The corrosion behavior and effects were evaluated in accelerated and simulated testing conditions by Electrochemical test system. Film hierarchy, amorphous carbon hybridization, and film contact angle also were investigated by SEM-EDX, XPS, Raman spectroscopy and contact angle tester. It shown excellent performance, far beyond technical

target of 2025 DOE (US Department of Energy). Film thickness impact was also discussed in this paper. Overall, Ta-C composite film shown promising mass production application prospect in PEMFCs industry.

Synthesis and Exploration of Heat Transfer Properties in Diamond-Like Carbon/Copper Composite Films Deposited on Stainless Steel Substrates

by MOHD SARIM KHAN | Dr. C Sasikumar | Maulana azad national institute of technology Bhopal |
Maulana azad national institute of technology Bhopal

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Keywords: DLC films, PECVD, diamond like carbon films, heat transfer, magnetron sputtering, thin films.

This study presents the synthesis of amorphous hydrogenated diamond-like carbon (DLC)/copper composite films on stainless steel and investigates their impact on heat transfer properties. Growth morphologies reveal the formation of nanocrystalline ballas-like diamond crystals on stainless steel substrates, suggesting radial crystal growth. Raman spectroscopy of the films detects the T2g vibration mode of diamond crystals alongside D and G bands from carbon ring breathing modes and sp² bonded carbon stretching vibrations. A downshift of the T2g peak to 1157 cm⁻¹ indicates nanocrystalline diamond. Additionally, Cu-O vibration peaks suggest atmospheric oxidation of copper on the surface. Raman mapping, based on intensities of Raman bands at 450 cm⁻¹ (Cu-O) and 1580 cm⁻¹ (E2g phonon mode of sp² bonded carbon), reveals uniform distribution of copper and DLC films. Coating the stainless steel surface with a diamond-like carbon/Cu composite film significantly enhances heat flux. While the uncoated surface exhibits a heat flux of 100 W/m², it increases to 450 W/m² after DLC/Cu composite coating.